A SYSTEM AND A METHOD FOR CLEANING PROCESS CHAMBERS AND VACUUM LINES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based on French Patent Application No. 02 14 571 filed November 21, 2002, the disclosure of which is hereby incorporated by reference thereto in its entirety, and the priority of which is hereby claimed under 35 U.S.C. §119.

BACKGROUND OF THE INVENTION

Field of the invention

The invention described in this document relates to the cleaning of process chambers and vacuum lines in installations for fabricating semiconductor components and microtechnology components.

Description of the prior art

SUMMARY OF THE INVENTION

Semiconductor components and microtechnology components are usually fabricated in a vacuum in a process chamber. The fabrication process comprises numerous steps, in particular chemical vapor deposition (CVD) steps in which one or more gases react with a solid surface to produce a solid phase deposit. Various solid layers can be deposited onto a semiconductor substrate in this way, for example to produce electrical circuits. However, the solid deposits are produced not only on the semiconductor substrate but also on the whole of the wall of the process chamber and on the wall of the vacuum line that generates and maintains the vacuum in the process chamber.

The same process chamber is used to fabricate successive batches of components by deposition on successive batches of semiconductor wafers. The solid deposit applied to the wall of the process chamber when fabricating one batch of components is liable to contaminate the semiconductor wafers of another batch subsequently introduced into the chamber for the next fabrication procedure. It is therefore necessary to preserve the purity of the process chamber to prevent contamination of one procedure by another. Process chambers are cleaned between two successive fabrication procedures.

For example, a solid deposit of silicon oxide (SiO_2) is produced in the high density chemical vapor deposition (HDPCVD) process and is removed

using nitrogen trifluoride (NF_3), which is a highly reactive gas. The NF_3 molecules are dissociated by the plasma to produce F_2 molecules and excited atoms of atomic fluorine F. The fluorine atoms react with the silicon oxide to produce silicon tetrafluoride (SiF_4) and other gas molecules. These gases are pumped out of the process chamber via the vacuum line. At present, an HDPCVD procedure takes several minutes to create a 7 500 Å layer of silicon oxide on a silicon wafer. The cleaning step between two deposition procedures takes several minutes to remove the undesirable layer of silicon oxide on the wall of the process chamber. The cleaning time is adjusted so that it is just sufficient to remove the layer of silicon from the wall of the process chamber without significantly attacking the metal of the process chamber wall.

At present the cleaning time is adjusted by trial and error, the approximate duration suited to the process used being determined experimentally over the course of several attempts. An adjustment must be effected for each type of process used. The method is tedious and cannot compensate quickly and effectively any variants, adaptations or drift of the processes.

The document US 2002/0020429 A1 proposes cleaning a process chamber using a remote plasma source that is less aggressive to the internal parts of the process chamber.

The document proposes determining the "endpoint" of the cleaning step by using a secondary test plasma source that is placed directly in the process chamber to generate a plasma from gases present in the process chamber and is associated with means for spectroscopically analyzing the test plasma generated in this way. The test plasma does not act on the walls of the process chamber, and its power must be sufficiently low for it not to affect the cleaning operation performed using the remote plasma source.

Cleaning is considered to be complete when the spectroscopic analysis means indicate that the intensity or ratio of the species or byproducts reaches a predetermined stable level, indicating that the chamber is completely clean.

The above technique is an indirect method which registers the absence of cleaning byproducts in the cleaning plasma generated by the remote plasma source.

The information provided by the test plasma generator is not reliable, because the result also depends on the remote plasma source itself, and on its cleaning capacity. Moreover, the method provides information only after complete cleaning of the process chamber, and cannot provide information on the progress of a current cleaning step. Another consequence of this is that the method is inaccurate.

The problem is to determine quickly, efficiently, and reliably the time needed to clean the process chamber sufficiently and not excessively. If the cleaning time is underevaluated, the silicon oxide layer on the process chamber wall is not removed completely. Conversely, overevaluating the cleaning time causes fluorine atoms to react with the metal of the process chamber wall itself.

Moreover, the cleaning gas NF_3 is costly, and it is beneficial to minimize the quantity used. A cleaning cycle uses approximately 3.5 liters of NF_3, which costs approximately 400 euros per kilogram. A cassette contains 25 silicon wafers, and a 22 kg cylinder of NF_3 is sufficient to clean the chamber during the processing of 84 cassettes. This corresponds to a cleaning cost per cassette of approximately 100 euros. This cost is not negligible, and it is beneficial to reduce it.

Moreover, the cleaning gas NF_3 is biologically harmful, and there is therefore an ecological benefit in reducing the quantity used, to prevent degrading the environment.

The invention aims to monitor the cleaning of process chambers and vacuum lines to provide just sufficient cleaning of the process chambers and vacuum lines, thereby preventing both insufficient cleaning and excessive cleaning. This assures a high quality of treatment processes carried out in the process chamber and minimizes the quantities of cleaning gas used. Monitoring must be fast, efficient and reliable, to allow adaptation to all types of process and to assure a high level of process flexibility.

Because cleaning is monitored in this way, less cleaning gas can be used, at the same time as preventing degradation of the process chamber and vacuum line walls.

Cleaning can also be automated, avoiding the need to rely on the experience of skilled operators to choose a satisfactory cleaning time.

The essential idea of the invention is to design a system for

determining directly the cleanliness of a process chamber or vacuum line, the system commanding continuation of the cleaning step for as long as the process chamber or the vacuum line is not sufficiently cleaned and interruption of the cleaning step as soon as the process chamber or the vacuum line is sufficiently cleaned.

To this end, a sensor tests the nature of a surface layer of a sample of the inside surface of the process chamber or vacuum line wall to detect the presence or the absence of atoms of a deposit layer.

SUMMARY OF THE INVENTION

To achieve the above and other objects, the invention provides a system for monitoring the cleaning of process chambers and vacuum lines, the system including a source of a test plasma, spectral emission measuring means receiving light from the test plasma, means for analyzing signals obtained from the spectral emission measuring means to determine the nature of the atoms present in the test plasma, and means for alternately exposing a sample of a process chamber or vacuum line inside surface to be monitored either to the gas inside the process chamber or vacuum line or to the test plasma from the test plasma source.

The test plasma acts on the surface sample to be tested, removing therefrom surface atoms that are excited in the test plasma and emit photons in a spectrum corresponding to the transition energy specific to each atom. It is possible to identify the atoms by using spectral emission measuring means to analyze the optical spectrum emitted, and the number of photons emitted is proportional to the number of atoms present in the sample analyzed.

The sample is representative of the state of the whole of the inside surface of the process chamber. The monitoring method is therefore direct, reliable, and accurate.

The monitoring system is relative bulky, and cannot be placed entirely and permanently inside a process chamber and directed toward the inside surface sample to be analyzed. It is therefore necessary to provide an interface intermittently connecting external spectral emission measuring means to the surface sample to be analyzed, which is necessarily oriented toward the interior of the process chamber.

A first embodiment uses a surface sample to be analyzed that is

mobile, being installed in the process chamber or vacuum line and movable between a first sampling state, in which the active surface of the surface sample to be analyzed is oriented toward the interior of the process chamber or vacuum line to expose it to the gases in the process chamber or vacuum line and to receive deposits, and a second sampling state, in which the active surface of the surface sample to be analyzed is oriented toward the exterior of the process chamber or vacuum line, facing the test plasma source, to expose it to the test plasma. In the first state, the surface sample receives a deposit, like all the other regions of the inside surface of the process chamber or vacuum line. In the second state, the surface sample is accessible so that it can be exposed to the test plasma.

A second embodiment uses a flexible optical fiber between external spectral emission measuring means and a test plasma source that can be moved in the process chamber or vacuum line so that the test plasma can be directed at predetermined times toward a region of the inside surface of the process chamber or vacuum line wall. The test plasma source assumes a first state away from the surface sample to be analyzed, to allow the gases in the process chamber or vacuum line to act on the surface sample to be analyzed, and a second state facing the surface sample to be analyzed, to allow the test plasma to act on the surface sample to be analyzed.

The system according to the invention preferably includes control means for receiving from the analysis means information relating to the nature of the atoms present in the test plasma in order to command continuation of the cleaning step for as long as the atoms present include atoms of deposits and to interrupt the cleaning step as soon as the atoms present no longer include atoms of deposit.

The invention also provides a method of cleaning process chambers or vacuum lines, the method including a cleaning step using one or more cleaning gases for decomposing deposits on interior walls of the process chambers or vacuum lines and one or more intermediate monitoring steps in which, using a monitoring system as defined above, the presence of atoms of deposit on at least a sample of an inside wall of the process chamber or vacuum line to be cleaned is detected by causing a test plasma to act on the deposit on the surface sample.

The intermediate monitoring steps can be carried out at

predetermined times.

The predetermined times are preferably chosen in the vicinity of a predictable end of cleaning time.

Other objects, features and advantages of the present invention will emerge from the following description of particular embodiments thereof, which is given with reference to the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagrammatic view of a process chamber and its monitoring means, showing a first embodiment of a cleaning monitoring system according to the present invention.

Figure 2 is a partial diagrammatic view of a first embodiment of a monitoring system according to the invention, shown in a cleaning position.

Figure 3 is a partial diagrammatic view of the figure 2 monitoring system, shown in a test position.

Figure 4 is a diagrammatic view of test and control means of one embodiment of the present invention.

Figure 5 is a partial diagrammatic view of a second embodiment of a monitoring system, shown in a test position.

Figure 6 is a partial view of the figure 5 monitoring system, shown in a cleaning position.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the embodiment shown in figure 1, the monitoring system is applied to a process chamber 1 associated with a vacuum line 2 including pumping means 2a for pumping gases out of the process chamber 1.

The monitoring system includes a test plasma source 3 for generating a test plasma 5. An interface 4 is used to direct the test plasma 5 toward a sample 6 of the inside surface of the process chamber 1 or the vacuum line 2 to be monitored. Spectral emission measuring means 7 measure the spectral emission of the test plasma 5.

Signals produced by the spectral emission measuring means 7 are sent to analysis means 8 which analyze the signals to determine the nature of the atoms present in the test plasma 5.

Control means 9 receive the signals from the analysis means 8 and monitor the continuation or halting of the step of cleaning the process chamber 1 or the vacuum line 2. To this end, the control means 9 control

solenoid valves 10 installed on a cleaning gas supply pipe 11 for conveying cleaning gases from a cleaning gas source 12 into the process chamber 1.

In accordance with the invention, means are provided for alternately exposing the surface sample 6 to the gases inside the process chamber 1 or vacuum line 2 and to the test plasma 5 fed from the test plasma source 3 via the interface 4.

Figures 2 and 3 show one particular embodiment of the test plasma source 3 in more detail. The test plasma source can be a plasma generator.

In this embodiment, the test plasma source 3 includes a sealed quartz tube having a first end 3a communicating with the atmosphere inside the process chamber 1 or the vacuum line 2 to be tested and a blind second end 3b. The tube is surrounded by a magnetic excitation antenna 13 associated with a radiofrequency generator 14 which feeds it with radiofrequency electrical energy to generate a test plasma 5 in the tube (figure 3).

This kind of plasma generator can operate over a range of internal gas pressures generally running from 100 Pa to 1 000 Pa.

The spectral emission measuring means 7, consisting of an emission spectrometer, for example, are disposed facing the blind end 3b of the tube of the test plasma source 3, to receive through the wall of the tube the light radiation 15 emitted by the test plasma 5 present in the tube.

Thus the light radiation 15 propagating from the test plasma 5 to the spectral emission measuring means 7 passes through the wall of the sealed quartz tube.

Consider next the first embodiment of the interface 4, which is described with reference to figures 2 and 3. In this first embodiment, the interface 4 is used to move a sample 6 of the inside surface of the process chamber 1 to be monitored between a first state shown in figure 2 and a second state shown in figure 3.

In the first state shown in figure 2, the surface sample 6 is oriented towards the interior of the process chamber 1 or the vacuum line 2 to be monitored, and is therefore exposed to the gases 16 in the process chamber 1 or the vacuum line 2, for example the cleaning gas such as NF_3. As a result, during active process steps, the surface sample 6 is exposed to the active plasma in the process chamber 1, which generates a deposit 6a on the

whole of the inside surface of the process chamber 1, and in particular on the surface sample 6. Then, during a step of cleaning the process chamber 1, the surface sample 6 is exposed to the action of cleaning gases 16 for eliminating the deposit 6a. The object of the invention is precisely to detect when the deposit 6a disappears because of the action of the cleaning gases 16.

In the second state, shown in figure 3, the surface sample 6 is oriented toward the exterior of the process chamber 1 or the vacuum line 2, facing the test plasma source 3 in order to be exposed to the test plasma 5. As a result, the test plasma 5 detaches from the surface sample 6 any atoms of the deposit 6a, those atoms generating spectral emissions that are contained within the light radiation 15 propagating toward the spectral emission measuring means 7.

In all embodiments, the surface sample 6 can have small dimensions, for example only a few millimeters.

In the embodiment of figures 2 and 3, the interface 4 can further include a closure flap 17 mobile between a position closing the first end 3a of the test plasma source 3 during cleaning or active process steps and a position opening the first end 3a during test steps, as shown in figure 3.

In the second embodiment shown in figures 5 and 6, the test plasma source 3 is itself movable in the process chamber 1 or the vacuum line 2, assuming a first state shown in figure 6 and a second state shown in figure 5.

In this embodiment, there is again a test plasma source 3, shown diagrammatically in the form of a tube having a first end 3a for communicating with the atmosphere inside the process chamber 1 or vacuum line 2 to be tested, with a magnetic excitation antenna (not shown) supplied with radiofrequency electrical energy by the radiofrequency generator 14.

Also shown again are the spectral emission measuring means 7, for example an emission spectrometer.

In the first state shown in figure 6, the test plasma source 3 is away from the surface sample 6 to be analyzed, which is a portion of the wall of the process chamber 1 or vacuum line 2. In this state, the gases in the process chamber 1 or vacuum line 2 act on the surface sample 6 to be analyzed. For example, the cleaning gases 16 progressively reduce the

deposit 6a on the surface sample 6 to be analyzed during the cleaning step.

In the second state shown in figure 5, the test plasma source 3 is inside the process chamber 1 or vacuum line 2, facing the surface sample 6 to be analyzed, so as to cause to act on the surface sample 6 to be analyzed the test plasma 5 generated by the radio-frequency generator 14 energizing the magnetic excitation antenna.

To allow the test plasma source 3 to move between the two states of the monitoring system, it is connected to the spectral emission measuring means 7 by a flexible optical fiber 19 which conveys light from the test plasma source 3 to the spectral emission measuring means 7. The flexible optical fiber 19 is associated with a flexible electrical supply line 20 that conveys the radiofrequency electrical energy from the radiofrequency generator 14 to the magnetic excitation antenna of the test plasma source 3.

In the first state shown in figure 6, the test plasma source 3 is inside a compartment 21 isolated from the action of the plasmas or cleaning gases 16 inside the process chamber 1 by the closure flap 17, which is operated by operating means 4b such as a motor or a piston-and-cylinder actuator. In the second state shown in figure 5, the test plasma source 3 is moved inside the process chamber 1 after the closure flap 17 is opened by operation of the operating means 4b. The test plasma source is moved by drive means 4c such as a piston-and-cylinder actuator, merely shown by arrows in figure 5.

In both embodiments, the operating means 4a and 4b, and where applicable the drive means 4c, such as motors or piston-and-cylinder actuators, move the monitoring system between its first and second states.

For example, in the embodiment of figures 2 and 3, the operating means include a first member 4a, such as a piston-and-cylinder actuator, for pivoting the surface sample 6 between the first state shown in figure 2 and the second state shown in figure 3, while a second member 4b, such as a second piston-and-cylinder actuator, pivots the closure flap 17 between the first state shown in figure 2 and the second state shown in figure 3.

The second embodiment of figures 5 and 6 again includes the closure flap 17 and its operating means 4b for opening or closing the compartment 21 providing isolation from the test plasma source 3, said test plasma source 3 being moved by the drive means 4c between its two states

shown in figures 6 and 5, respectively.

In operation, the process chamber as shown in figure 1 receives one or more semiconductor wafers 18. During active process steps the semiconductor wafers 18 are subjected to chemical deposition, etching and other steps using active plasmas generated by a main plasma source in the process chamber 1. These steps produce solid deposits such as the deposit 6a over the whole of the inside surface of the process chamber 1 and in particular on the surface sample 6.

To prevent subsequent pollution of the semiconductor wafers 18 by these deposits, which are liable to be released into the atmosphere inside the process chamber 1, cleaning steps are carried out, during which one or more cleaning gases 16 are caused to react, by admitting cleaning gas from the cleaning gas source 12 into the process chamber 1 by opening the solenoid valve 10, whereupon the cleaning gas flows via the cleaning gas supply pipe 11. The solenoid valve 10 is opened by the control means 9.

The cleaning gas 16 then progressively cleans the inside surface of the process chamber 1, and in particular that of the surface sample 6.

During active process steps and cleaning steps, the interface 4 is in its first state, in which the surface sample 6 is subjected to the action of the active plasmas or cleaning plasmas in the process chamber 1.

The cleaning phase includes one or more intermediate monitoring steps using monitoring systems as previously described and seeking to detect deposit atoms on the surface sample 6. To this end, in each intermediate monitoring step, the control means 9 cause the operating means 4a and 4b and where applicable the drive means 4c to move the interface 4 from its first state to its second state, so that the surface sample 6 is exposed to the action of the test plasma 5.

For example, in figures 2 and 3, the operating means 4a and 4b cause the surface sample 6 to pivot toward the test plasma source 3 and the closure flap 17 to pivot away from the test plasma source 3. In figures 5 and 6, the drive means 4c move the test plasma source 3 from its first state shown in figure 6 to its second state shown in figure 5 and the operating means 4b cause the closure flap 17 to pivot.

Then, during the intermediate monitoring step, the control means 9 cause the radiofrequency generator 14 to operate, which excites the gases

inside the tube of the test plasma source 3 to generate the test plasma 5. The test plasma 5 then operates on the deposit 6a on the surface sample 6, releasing atoms which are then excited and produce light 15 perceived by the spectral emission measuring means 7, which then sends signals to the analysis means 8, which determine the nature of the atoms present in the test plasma and communicate that information to the control means 9.

If the signals indicate the presence of deposit atoms, the control means 9 continue the cleaning step, after causing the operating means 4a and 4b to return the interface 4 to its first state and thereby to subject the surface sample 6 to the action of the cleaning gases 16, for a particular time at the end of which an intermediate monitoring step is begun under the same conditions as above.

If, during an intermediate monitoring step, the control means 9 receive information to the effect that there are no further deposit atoms, then the control means 9 operate the solenoid valve 10 to interrupt the admission of cleaning gases and end the cleaning step. The control means then return the interface 4 to its first state, in order to return the process chamber 1 to its operational state for active process steps.

During the intermediate monitoring steps, it is also possible to detect that the quantity of deposit atoms has fallen below a predetermined threshold, indicating that cleaning will soon be finished. In this case, the control means 9 can simply continue the cleaning step for a predetermined time, estimated for the cleaning to be sufficient and then interrupted.

Figure 4 is a general diagram of the operating means of the device from figures 1 and 3 and 5 and 6.

Thus it shows again the spectral emission measuring means 7, such as an emission spectrometer, which send their output signals to the analysis means 8, which determine the nature of the atoms present in the test plasma 5. The analysis means send their signals to the control means 9 which operate, firstly, on the solenoid valve 10 to continue or interrupt the cleaning step, and which operate on the operating or drive means 4a (and/or 4b and/or 4c) to modify the state of the monitoring system in the process chamber 1. The control means 9 also operate on the radiofrequency generator 14 to energize the magnetic excitation antenna 13 that excites the atoms of gas in the test plasma source 3 to generate the test plasma 5.

Thanks to the invention, the cleaning of the process chambers and vacuum lines can be monitored efficiently, preferably ensuring sufficient but not excessive cleaning, regardless of the process that previously generated the deposit to be cleaned, and regardless of the cleaning process.

The present invention is not limited to the embodiments that have been described explicitly, but includes variants and generalizations thereof that will be evident to the person skilled in the art.